SALTON SEA ECOSYSTEM MANAGEMENT PLAN

Draft Report on Selenium at the Salton Sea and Summary of Data Gaps

February 2005

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DRAFT REPORT ON SELENIUM AT THE SALTON SEA AND SUMMARY OF DATA GAPS

The Department of Water Resources (DWR), in conjunction with the Department of Fish and Game (DFG), is preparing a Salton Sea Ecosystem Management Plan and accompanying Programmatic Environmental Impact Report (PEIR) on behalf of the Secretary of Resources, in compliance with legislation enacted in 2003. This report provides a brief summary of available information regarding environmental concentrations of selenium in and around the Salton Sea (Figure 1), describes ongoing studies, and identifies additional data needed to complete the baseline selenium risk assessment for ecological and human receptors at the Salton Sea. While this report focuses on selenium conditions in abiotic media (i.e., water, soils, and sediments), biotic media also are summarized because of their importance to understanding the distribution, cycling, and exposure pathways for selenium in the Salton Sea and surrounding habitats. This report also addresses the adequacy of existing data for evaluating human health risks from dietary exposures to selenium. The data gaps analysis is intended to assess the importance of additional data collection and analysis to development and evaluation of ecosystem management alternatives.

RELATION OF SELENIUM TO ECOSYSTEM MANAGEMENT ACTIVITIES

A number of restoration options have been put forward and described in various documents (Pacific Institute 2001; US Filter Corporation 2002; Tetra Tech 2004a; U.S. Bureau of Reclamation [Reclamation] 2003). In turn, the ecological implications of these various proposals also have been assessed by a number of stakeholder groups (Selenium Workshop 2003, Tetra Tech 2003). It is likely that many of the conditions created by these options would occur among the range of alternatives to be evaluated in the Management Plan and PEIR.

The potential ecological effects of the various Salton Sea restoration proposals were evaluated in workshops (Salton Sea Science Office [SSSO] 2001, 2002, 2003, 2004; UC-Riverside 2001), by contractors (Tetra Tech 2000a, 2003, 2004), in technical comments from regulatory or resource agencies (Presser 2003, 2004; Reclamation 2000), and by groups of researchers (San Diego State University [SDSU] 2002). In general, it is recognized that altering conditions under various options would have environmental consequences that affect selenium concentrations, transformations, and wildlife exposures. In addition, human health impacts associated with increasing selenium concentrations in sport fish, and potentially with fugitive dust from exposed/dried sediments from the future Salton Sea, were recognized.

The following general consensus was established for selenium in the Salton Sea at a meeting of scientists knowledgeable about the environmental chemistry of selenium (SSSO 2003):

- Current inflows to the Salton Sea contain low to moderate levels of selenium. However, the total selenium load to the Salton Sea annually is equivalent to that of the former Kesterson Reservoir during its operation.
- The existing Salton Sea appears to accommodate selenium as shown by lower water-borne concentrations relative to inflows. This selenium accommodation could occur by dilution, incorporation into sediments, or some other unknown process.
- Phytoplankton and algae take up selenium, but the absence of vascular plants in the Salton Sea tends to decrease selenium bioavailability. Alternatives that include a fresh-water component would support vascular vegetation, and thereby increase the bioavailability of selenium. Current selenium levels in fish (from human health advisories) and some birds are of concern.

- Selenium is currently bioavailable through invertebrate and fish consumption of bacteria and algae in the water column or in shallow sediments. The greatest portion of selenium appears to become incorporated into deep, anoxic sediments as the algae and bacteria die, becoming a detrital ‘rain’. These deep selenium sinks have little or no biological activity. Therefore, the selenium essentially remains biologically unavailable as long as deep water and anoxic sediment conditions are maintained.
- If management options that rely on desalination by reverse osmosis are implemented, then increased levels of selenium would be expected in most components of the ecosystem. These would require selenium treatment and removal.
- If alternatives were constructed that included playas, selenium levels in the playas (areas surrounding the brine pool) would be expected to be very high (in some cases in excess of 1000 µg/L [equivalent to parts-per-billion, or ppb]) in pooled puddle water from irrigation or rainfall. Group consensus was that irrigation associated with vegetation for dust control would result in selenium mobilization conditions far exceeding Kesterson Reservoir conditions.
- Tailwater reductions along drains that are tributary to the New and Alamo Rivers are expected to increase selenium concentrations in water to roughly 12 µg/L. If desalination is implemented, it would concentrate some of the inflow flowing into the North Sea alternative by a factor of 3 (to 36 µg/L). The US Filter version would increase selenium from 12 to 15 µg/L through evapo-concentration.
- Selenium is of concern in the water column and underlying sediments, but is also of concern in exposed sediments that may become fugitive dust in the exposed sediment playas that would be irrigated to promote vegetation establishment. This problem would be most acute if the northern portion of the Salton Sea were exposed.

While various proposals have undergone evaluation by different groups, it is recognized that the ultimate result of any option will not be fully known until the final ecosystem management decisions are instituted.

EXISTING SELENIUM INFORMATION FOR SALTON SEA

The following summary was developed through review of available published and unpublished sources, as referenced. Additional information was obtained from meetings at the DWR on August 6, 2004, and at the SSSO on August 18, 2004. Inputs to the data-gathering process were solicited from the following agencies: DWR, U.S. Geological Survey/SSSO, Reclamation, U.S. Fish and Wildlife Service (USFWS), DFG, and the California EPA Office of Environmental Health Hazard Assessment (OEHHA).

In addition to hard-copy books and reports, relevant published and unpublished data were derived from information provided on various federal and state agency websites as follows (hardcopies of these reports were downloaded for this report and are maintained in a separate file):

- U.S. Bureau of Reclamation [http://www.usbr.gov/lc/region/saltnsea/pub_info_mat.html]
- U.S. Geological Service archived documents [http://www.usgs.gov/pubprod/]
- California Department of Fish and Game [http://www.dfg.ca.gov] search site for ‘Salton Sea’
- Toxic Substances Monitoring Program [http://www.swrcb.ca.gov/programs/smw/]
- Salton Sea Authority [http://www.saltonsea.ca.gov]
- California EPA OEHHA Fish Advisory [http://www.oehha.org/fish/special_reports/consumexec.html]
- California State University at San Diego, Center for Inland Waters [http://www.sci.sdsu.edu/salton/SaltonBasinHomePage.html]

- Pacific Institute [http://www.pacinst.org/topics/water_and_sustainability/salton_sea/].

The available data were reviewed for their applicability to the assessment of risks from selenium in the Salton Sea ecosystem. The type and quality of data required depends on the type of evaluations to be made or the decisions to be taken. Typically, the environmental studies that are intended to support this evaluation/decision process are planned with consideration of the Data Quality Objectives (DQOs), as documented by U.S. EPA guidance (2000b). While these DQOs could be applied to any future studies, we are limited by the data quality approaches already applied in the previous studies. Many of the data summarized in this report are taken from peer-reviewed articles, while others have been extracted from consultant reports, published and unpublished agency reports, and laboratory data summaries with no supporting information. The documentation of data quality varies from source to source. The representativeness of the sampled media to different areas of the Salton Sea ecosystem also must be considered (due to limited sample numbers, limited sampling areas, etc.). In addition, it also is necessary to determine whether historic sample results are still representative of current conditions. These factors were considered in the identification of data gaps and will be accounted for in the risk analysis evaluation.

For the purposes of this report, the following three categories (qualified with letters A, B, and C) were used to represent the different quality assurance/quality control (QA/QC) levels data obtained from the various reports:

A. Data that were collected under a sampling and analysis plan (SAP), had full data validation, or were included in a published agency report or peer-reviewed publication.

B. Data that have been collected by a public agency or other group (i.e., university or consultant firm) with QA/QC procedures, but where QA/QC results have not been formally assessed in the referenced document. This group also includes drafts of peer reviewed articles or manuscripts.

C. QA/QC methods not ascertainable or non-existent.

It is presumed that data used in fully reviewed documents, such as agency or peer review publications, are of the highest quality. The USFWS's Patuxent Analytical Control Facility is responsible for contracting all sample analyses for USFWS through certified laboratories and also completes data validation for unpublished USFWS reports (pers. com., Carol Roberts, USFWS), including Audet et al. (1999), Roberts (1997), Roberts and Berg (2000), and Skorupa (2003). Lower QA/QC data levels are assigned when specific results of the data quality assessment are not provided in the report or when no QA/QC information is provided. The results of this general QA/QC assessment are provided in the footnotes of the report-specific data tables in Appendices A, B, C, and D. The QA/QC data group designation can be coded as a field within the electronic database that will be created for future risk analyses.

The following summaries are intended to document the importance of each environmental medium and what is currently known about selenium in the Salton Sea area in each of the media under existing conditions. In order to avoid duplication, the specifics about concentration of selenium in these media are provided in the associated, referenced tables and are not repeated in the text. The selenium data have been collected from various studies within the Salton Sea area in order to identify the available data and the potential data gaps for future evaluations of risks from selenium. The data gaps that were identified by this process are summarized at the end of this report. These data gaps relate to descriptions of existing conditions; additional data gaps may be identified once the ecosystem management decisions have been finalized.

Abiotic Environmental Media

Abiotic or 'non-living' environmental media of interest for risk assessment include surface water, sediments, and soils. Data from different studies that measured selenium concentrations in water are presented in Appendices A, B, and C and summarized in Table 1 (surface water), Table 2 (sediments), and Table 3 (soils). The summaries of existing data are used to determine where selenium information in different media may be lacking. These data gaps are then grouped according to their relative importance for the assessment of risks associated with various ecosystem management alternatives.

Surface Water

Surface water sources for the Salton Basin represent most of the past and future source of selenium in the Salton Sea. Selenium may be removed from the water column by various biotic and abiotic processes, resulting in secondary sources in other environmental media (e.g., sediments and aquatic invertebrates). Under certain conditions, selenium may also be re-mobilized from sediments into surface water. For these reasons, assessments of selenium conditions in the environment typically begin with an assessment of surface water quality.

Surface water samples have been analyzed in various studies of the Salton Sea and its tributaries (Table 1). Water from the Colorado River is used to irrigate agricultural lands in the Imperial and Coachella valleys, and some of that water enters the Salton Sea through drainage from those agricultural areas. This process alters the chemistry of the agricultural drainage by increasing the concentrations of nutrients, trace elements, and organic compounds. Surface water quality in agricultural drains has been measured directly in a number of the drains and indirectly in samples collected in the tributary rivers (Alamo, New, and Whitewater). In general, the measured selenium concentrations are highest in the agricultural drains where the greatest amount of variability was also observed.

Selenium concentrations in the surface water of the tributary rivers are typically not as high as concentrations seen in the agricultural drains because of dilution. Selenium concentrations in the New and Alamo rivers also have been shown to increase as the water passes through agricultural areas in the Imperial Valley. There are only slight apparent differences in mean selenium concentrations among the three rivers. The Alamo River tends to have the highest mean selenium concentrations (ranging from 3 to 8 µg/L), with the New River having the next-highest mean selenium concentrations (ranging from 2 to 4.3 µg/L). While there are not as many data available for the Whitewater River, the reported concentrations range from 2.4 to 3.15 µg/L.

The selenium concentrations in the Salton Sea surface water are lower than those observed in the tributary rivers. The levels are reported to be between 1 and 2.02 µg/L (Setmire et al. 1990, Holdren and Montano 2002, and UC-Riverside 2003). The lower selenium concentrations in the Salton Sea surface water are probably the result of sequestration in the anoxic deep sediments on the Salton Sea's floor (SSSO 2003).

There were more studies in which surface water samples were collected for the tributary rivers and drains than for the Salton Sea. Overall, the sampling of surface water appears to be sufficient to assess risk.

Sediment

Information about current selenium concentrations in Salton Sea sediments is required to understand selenium cycling and to analyze potential ecosystem management alternatives. The distribution of selenium in sediments may also indicate if there are areas where elevated selenium 'hot spots' may affect decisions about ecosystem management alternatives. It is especially critical that the available sediment data be well distributed around the Salton Sea in order to strengthen the ability to predict the selenium effects of various ecosystem management decisions. Therefore, it is important that data sufficiently represent the horizontal and vertical sediment concentrations of selenium in areas under consideration for ecosystem management alternatives.

Sediments in the Salton Sea may be a current sink for selenium entering through agricultural drainage and suspended sediment. These same sediments might also represent a reservoir of selenium that could be remobilized to surface water if the elevation of the Salton Sea is significantly lowered in the future. In a shallower Salton Sea, fine selenium-rich sediments could be mobilized into the water column by the action of wind-driven waves or boat wash. Sediment selenium concentrations also are important to understanding transformations that would occur in near-shore areas where the sediment might be exposed as the water surface elevation is lowered. It is possible that subsequent wetting of the exposed sediments, from rainfall or from irrigation for vegetation establishment, could mobilize significant quantities of selenium. The SSSO (2003) recognized the potential for this condition at the Salton Sea and considered the potential to exceed even the selenium-release conditions observed in ephemeral, rain-fed pools at Kesterson Reservoir (Byron et al. 2003).

A preliminary mass balance for selenium in the Salton Sea, conducted by Schroeder et al. (2002), showed the importance of the anoxic sediments on the Salton Sea's floor as a sink for selenium entering from the aerobic New and Alamo Rivers surface water. Consideration of re-mobilization of deposited selenium and subsequent environmental exposures will be important in the analysis of ecosystem management alternatives.

In contrast to surface water, selenium concentrations in Salton Sea sediments tend to be higher than those observed in the tributary rivers (Table 2). The Lower Colorado River sediments were found to be very low (<0.1 μg/g to 0.9 μg/g dw) (Setmire et al. 1990, Schroeder 2004). Similarly low selenium concentrations were found in sediments from the rivers and creeks that flow into the Salton Sea. Salton Sea sediment samples showed a wider range of selenium concentrations than those observed within the river systems with reported concentrations from 0.191 μg/g dw (near Obsidian Butte) to 11 μg/g dw (near the Whitewater River delta). Other studies also have considered the variability in the distribution of selenium in Salton Sea sediments (Levine Fricke 1999, Vogl and Henry 2002) and concluded that the highest apparent selenium concentrations are in the northern Salton Sea Basin.

Until recently, the coverage of sediment samples around the Salton Sea was limited. In 2004, approximately 200 near-shore sediment samples were analyzed for total selenium by the SSSO and USGS and is further described in the "Studies in Progress" Section. These new data, when available, will significantly augment the information on near-shore sediments and how they may be affected by different ecosystem management alternatives. It is likely that more information on deeper anoxic sediments may be required. Sediment sampling in the tributary rivers appears to be adequate.

Soils

Selenium concentrations in soils of the Salton Basin are important because they represent a potential selenium source for the Salton Sea. This is especially true in the irrigated farming areas of the Imperial and Coachella valleys, where drainage water could become enriched in selenium before draining to the Salton Sea. Characterization of the selenium 'reserve' in these soil systems is important for the evaluation of any upstream, source control alternatives. This selenium reserve may be related to different depositional layers within the soils anywhere from the surface to the depth of tile drainage that could be correlated with soil mapping units across the farmed areas. It is expected that this information would be used to evaluate selenium source-control options in these areas.

The available selenium data for soils include a study for agricultural fields in the Imperial Valley (Schroeder et al. 1993) and a study from a focused, non-agricultural area near the southwest portion of the Salton Sea (Gersberg and Wright, undated). In addition, a formal request for additional data from the Coachella Valley agricultural areas has been made to the Coachella Valley Water District. These data, when received, will be provided in complete form in Appendix C and will be summarized in Table 3 in the Final Report.

Aquatic Biota

Data from different studies that measured selenium concentrations in biota are summarized in Table 4. As previously mentioned, biota data are included in this report because of their importance in selenium transformations, cycling, and transfer within the Salton Sea ecosystem, and for evaluation of selenium-associated risks.

Generalized trophic and bioaccumulation relations among organisms of the Salton Sea are presented in Figure 2. Figure 3 shows similar relationships for rivers and drains in the Imperial Valley. These figures present a simplified view of the potential ways by which selenium is transferred in different parts of the Salton Sea ecosystem and how ecological and human receptors may be exposed to selenium through the consumption of waterfowl or fish. Cycling and exposure pathways represented in these figures provide an important first step in developing conceptual site models for different parts of the Salton Sea ecosystem that will be used in the selenium risk assessments.

Concentrations in biota tissues can be expressed either on wet-weight or fresh-weight basis (which are considered to be synonymous), or on dry-weight basis. Conversion from one basis to the other is a function of the moisture content in the sample, as follows:

$$\text{Dry-weight conc.} = \text{Wet-weight conc.} \times \frac{100}{(100 - \text{Moisture percentage})}$$

For example, 10 μg/g on wet-weight (ww) basis in a sample having 80 percent moisture is equal to 50 μg/g on dry-weight (dw) basis. When selenium concentrations in tissue were originally reported in ww, the approximate dw concentration is presented in this summary.

Algae and Emergent Plants

Algae and plants take up selenium from surface water or sediments. These organisms are, in turn, direct food sources for aquatic invertebrates, fish, or birds. As such, they represent a direct pathway by which selenium enters into the food chain.

Samples of algae in the Salton Sea include blue-green, filamentous, and tubular algae with selenium concentrations ranging from non-detect to 1.8 μg/g dw. Emergent plant samples come from freshwater areas and include cattails and sago pondweed and various composites of cattails, bulrush, sorrel, and spikerush whose selenium concentrations range from non-detect to 5.02 μg/g dw.

Overall, the sampling of plants and algae is very limited, and additional sampling is planned for Spring 2005. These new sample results will be integrated with the existing data into a database that will be used to characterize risks.

Benthic and Aquatic Invertebrates

Benthic or aquatic invertebrates may also take up selenium from surface water or sediments. In addition, they are primary consumers of algae and plants and can accumulate significant quantities of selenium. Because they are an important food source for fish and birds, they represent a pathway by which selenium may bioaccumulate in the Salton Sea ecosystem. Some invertebrates such as crayfish and clams may also be eaten by humans, which could contribute to human health risks.

Benthic and aquatic invertebrate samples from the Salton Sea include pileworms and waterboatmen and composites of these species with amphipods, with selenium concentrations ranging from 0.82 to 12.1 μg/g dw. Aquatic invertebrates from freshwater areas are comprised of crayfish (ranging in selenium concentrations from 2.4 to 3.7 μg/g dw) and river clams (ranging in selenium concentrations from 0.71 to 15.8 μg/g dw).

A review of the data described above indicates that the number and diversity of aquatic invertebrate samples is limited for both the Salton Sea and its associated freshwater habitats. Additional sampling of these organisms is planned for Spring 2005. These new sample results will be integrated with existing data into a database that will be used to characterize risks.

Fish

Fish represent higher-level or secondary consumers that accumulate limited amounts of selenium from surface water or sediments but more significant quantities from their food sources. Because fish provide an important food source for larger fish and for fish-eating birds (i.e., forage fish), they represent another pathway by which selenium might bioaccumulate in the Salton Sea ecosystem. Some sport fish also are eaten by humans and can contribute to health risks. Existing fish samples, collected throughout the Salton Sea Basin, have been used for evaluation of human health risks, as noted in a subsequent section (Human Health Risk Assessments).

Fish samples may be analyzed as whole fish or as fillet (or muscle) samples and may be reported on a dry-weight or wet-weight basis (as noted above). Different fish species that have been sampled in the Salton Sea include bairdiella, corvina, mudsucker, sargo, and tilapia. Selenium concentrations among these samples ranged from 1.36 μg/g ww (about 6.5 μg/g dw) to 16.0 μg/g dw. Freshwater and delta fish samples include corvina, carp, catfish, largemouth bass, mudsucker, mosquitofish, sailfin molly, red shiner, tilapia, and yellow bullhead. Selenium concentrations among these fish samples from freshwater areas ranged from non-detect to 17.3 μg/g dw.

Selenium results are available for a wide variety of fish samples from the Salton Sea Basin, but some species are represented by relatively few samples, and most were collected several years ago. Additional analyses of archived and newly collected fish samples is planned for Spring 2005. The adequacy of existing and upcoming data for ecological risk assessment cannot be determined until ecological end receptors are selected for the conceptual site model and food web. Thus, ecological risk assessments are not necessarily compromised by insufficient data on some of the fish species found in the watershed. These assessments rely primarily on the quality and quantity of available data that represent the most significant exposure pathways from selected prey items. Use of fish tissue data for present and future ecological and human health risk assessments also may be constrained by the reported fluctuations in fish populations in response to various factors, such as the changing salinity regime, dissolved oxygen concentrations, and temperature, of the Salton Sea.

Amphibians and Reptiles

Similar to fish, amphibians and reptiles that use aquatic habitats in the Salton Sea ecosystem represent secondary consumers of plants and invertebrates, and serve as potential food sources for larger aquatic or semi-aquatic animals. They also can accumulate selenium from terrestrial or aquatic environments or be consumed in those environments. For these reasons, they are a significant link for understanding selenium transfers in the Salton Sea ecosystem.

Amphibian and reptile samples are comprised of bullfrog and spiny softshell turtles that were collected from the New and Alamo rivers and various creeks and drains. Selenium concentrations among these samples ranged from 0.79 μg/g ww to 14.0 μg/g dw. (Moisture was not found for the value reported here as ww.)

The bullfrog concentrations are based on only two samples while the turtle samples were more numerous. Assuming that the species sampled represent the most abundant and important amphibians and reptiles present in the tributary rivers to the Salton Sea, the sampling for these resources appears adequate to assess selenium risks.

Birds

Birds represent an important link in the Salton Sea ecosystem. In addition to the important role they play in public perception and recreational opportunities at the Salton Sea (e.g., hunting or birdwatching), they are important to the understanding of selenium in the food web. Because of their feeding habits, certain aquatic birds (such as ducks), might be highly exposed to selenium. By feeding at higher trophic levels in the food web, they may consume food sources that already have elevated selenium concentrations. These factors can result in significant accumulations of selenium in birds at levels that can impair reproduction or perhaps increase their susceptibility to disease or predation.

Many birds in the Salton Sea Basin are considered to be semi-aquatic because of their joint use of aquatic and terrestrial habitats. For the purpose of this report, they are considered among the aquatic organisms. Bird samples are analyzed as egg contents, liver, muscle, or whole-body (carcass) tissue depending on the use of the data for assessment of risks to ecological receptors or human consumers.

Selenium levels in birds were measured in eggs, muscle, kidney, liver, or carcass tissues. Bird egg samples include the following species: American coot, black-crown night-heron, black-necked stilt, black skimmer, Caspian tern, common moorhen, great egret, pied-billed grebe, snowy egret, and white-faced ibis. Selenium concentrations among these samples ranged from 0.54 μg/g to 35.0 μg/g dw. Muscle samples have been collected from northern shoveler and ruddy duck and ranged in selenium concentrations from 2.7 to 12.0 μg/g dw. Liver or kidney samples have been collected from American coot, black-necked stilt, brown pelicans and white pelicans, cattle egret, double-crested cormorant, eared grebe, great blue heron, northern shoveler, ruddy duck, and white-faced ibis. Selenium concentrations among these samples ranged from 2.7 μg/g to 56.2 μg/g dw. Carcass samples were collected for black-necked stilt, white-faced ibis, and Yuma clapper rail with selenium concentrations ranging from 3.2 to 11.3 μg/g dw.

Overall, the number and diversity of bird species samples appears to be adequate to assess selenium risks for ecological risk assessments. However, information to evaluate the importance of human consumption of waterfowl as an exposure pathway for selenium in human health risk assessments is unavailable.

Terrestrial Biota

Because terrestrial habitats around the Salton Sea have different selenium exposure conditions than those found in the aquatic habitats, it is important to develop an understanding of the levels of selenium in these media as well. The data will be subjected to the same type of risk-based analyses, including the development of a conceptual site model, to determine if selenium represents significant risks to terrestrial organisms of the Salton Sea ecosystem.

It should be noted that the following data for terrestrial organisms were developed from a single report by Gersberg and Wright (undated). All of these samples were collected in a focused, non-agricultural upland area near the southwestern portion of the Salton Sea. No similar assessment of terrestrial organisms have been conducted within the agriculturally active areas of the Salton Sea Basin. The development of conceptual site models for terrestrial biota may indicate that additional data are required for terrestrial organisms in agricultural areas.

Plants

Similar to the aquatic plants, terrestrial plants also provide an entry for selenium into Salton Sea animals that might consume them. Understanding selenium uptake in plants is especially important for evaluating options for vegetation control on future exposed sediments.

Leaves of the following terrestrial plants were analyzed: iodine bush, four-wing saltbush, alkali goldbush, creosote bush, and tamarisk. The geometric mean selenium concentrations of these samples ranged from 0.29 to 7.91 μg/g dw. Adequacy of this information for ecological risk assessment is unknown until the conceptual model for alternatives can be developed and ecological receptors have been selected.

Invertebrates

Similar to the aquatic invertebrates, terrestrial invertebrates are primary consumers of plant and soil food sources. As such, they also provide entry for selenium into terrestrial animals and link to certain aquatic consumers, such as birds.

Terrestrial invertebrate samples include whole body samples of beetles and ants. The geometric mean selenium concentrations of these samples ranged from 1.15 to16.2 μg/g dw. Adequacy of this information for ecological risk assessment is unknown until the conceptual model for alternatives can be determined.

Reptiles

Similar to aquatic amphibians and reptiles, their terrestrial counterparts also represent secondary consumers of plants and invertebrates that use terrestrial habitats in the Salton Sea ecosystem. They also serve as potential food sources for larger terrestrial and semi-aquatic organisms, such as birds.

Terrestrial reptile samples include iguana liver, muscle, and tails, and lizard muscles. The selenium concentrations for these samples ranged from 0.91 to 5.27 μg/g dw.

The adequacy of these data will be assessed during the development of the conceptual site model and selection of ecological receptors. If required to reduce uncertainty, additional sampling of these organisms may be recommended.

Birds

No selenium data were available for terrestrial birds from the Salton Sea area. If terrestrial birds are identified as an important ecological receptor during the development of the conceptual site model, then additional focused sampling of these organisms could be recommended at a future date.

Mammals

Small and large mammals in the Salton Sea terrestrial habitats represent higher order trophic organisms that could be potentially subject to significant selenium bioaccumulation. As shown in Figure 3, these organisms also might have feeding relations linked to aquatic organisms (such as birds feeding on mice, or raccoon feeding on crayfish) that could represent viable pathways for selenium transfer through the food web.

Terrestrial mammal samples include liver and muscles from two types of kangaroo rat (*Dipodomys merriami* and D. *deserti*). The selenium concentrations for these samples ranged from 0.93 to 5.11 μg/g dw.

The adequacy of these data will be assessed during the development of the conceptual site model and selection of ecological receptors. If required to reduce uncertainty, additional sampling of these organisms may be recommended.

Human Health Risk Assessments

Existing fish samples, collected in 1998 at three locations in the Salton Sea Basin (Red Hill Marina, Bombay Beach, and the State Recreational Area Headquarters), were used by Moreau et al. (in press) to evaluate the human health risks from selenium and other contaminants for tilapia fillets. A similar effort is in progress for three other fish species that could be consumed by local fishermen (Moreau et al. in review). Results from Moreau et al. (in press) were based on an average selenium concentration of 1.67 μg/g ww measured in 24 samples. The study concluded that a 70-kg adult could safely consume up to 1,000 g of tilapia per week (19 8-oz meals per month) and that children weighing 30 kg or more could safely eat up to 430 g per week (16 4-oz meals per month). Study results are consistent with a previous study (Costa-Pierce et al. 2000), indicating that selenium exposure through the consumption of Salton Sea fish should be limited to 130 to 190 g/day for a 70-kg adult. The Moreau et al. results are less conservative than current U.S. EPA (2000a) guidelines for selenium exposure via fish consumption. U.S. EPA allows up to 16 227-g (8-oz) meals per month or 1 meal per day for an average 70-kg adult consuming fish with an average selenium concentration of <2 μg/g.

Existing fish fillet data may be adequate for characterizing human health risks providing these data are representative of current conditions. However, refinements of existing health risk results to reflect current conditions require information on the present catch and consumption rates of sportfish. Also, accurate characterization of health risks could benefit from empirical information on the bioavailability (i.e., transfer efficiency) of selenium to humans from fish consumption. The bioavailability from fish consumed by humans was estimated at 100 percent by previous investigators, which may over-estimate actual exposure.

STUDIES IN PROGRESS

Discussions with SSSO and Reclamation staff indicate that a number of studies are currently in progress that may directly or indirectly address significant data gaps for the assessment of selenium risks in the Salton Sea ecosystem. The results of some of these studies may be available in time for use in evaluating ecosystem management alternatives in the PEIR.

One study in progress by the SDSU Graduate School of Public Health addressed the human health implications of eating fillets of tilapia caught in the Salton Sea (Moreau et al., in press) using existing fish tissue sample results. A similar study is in progress (Moreau et al. in review) for three other sport species in the Salton Sea (bairdiella, orangemouth corvina, and sargo) and data have been provided for nine other fish species (channel catfish, carp, tilapia, sailfin molly, red shiner, largemouth bass, mosquitofish, mosquitofish/sailfin molly composite, yellow bullhead, and grass carp) in the tributaries (Moreau 2004). The tissue results for the nine fish species were compiled primarily from existing sample results from the Toxic Substances Monitoring Program but also included several tissue samples for tilapia and sailfin molly from U.S. Geological Survey study samples (1986 and 1989). It is uncertain when a publication assessing the associated human health risks for these fish tissue data will be available.

The SSSO and USGS have contracted to analyze sediment samples collected along a large number of depth transects. Approximately 800 sediment samples were collected at 5-foot depth intervals along the shoreline during the 2003 water year as part of a study by Chris Holdren/Reclamation in Denver. These transects extend at regular intervals around the entire perimeter of the Salton Sea. Funding was secured to analyze about 200 of the archived samples for total selenium that were originally collected near the river deltas and other areas with gradual bottom slopes because of their importance to ecosystem management. The additional sediment samples were chosen to give more spatial coverage in other areas of the Salton Sea where lower water elevations will expose sediments. This information will help to better characterize the sediments around the margin of the Salton Sea and to help understand how these areas may respond to ecosystem management. These data, when available, will be included in Appendix B and summarized in Table 2 in the Final Report. If project managers and reviewers consider that additional sediment characterization is required, more of the original archive samples could potentially be analyzed.

Deep core samples also have been collected by URS for geotechnical evaluations associated with proposed dike locations. It is expected that surface portions of these archived core samples will be analyzed for selenium along with the transect samples.

An ongoing study to evaluate contaminant levels in bird eggs (great egret, black-crowned night-heron, and black-necked stilts) is being conducted by Chuck Henny/USGS from Corvallis, OR. The collected egg samples include great egrets and black-crowned night-herons from the north end of the Salton Sea and stilts from both the north and south ends of the Salton Sea. Although planned as part of this study, collection efforts did not yield enough avocet eggs for analysis. The samples have already been sent to a laboratory and the results could be made available in time for incorporation into the risk assessments for the Salton Sea. This study is a follow-up to previous studies by Ohlendorf and Marois (1990) and Bennett (1998).

Studies also are being conducted at UC Riverside to evaluate the use of chemical flocculents (polyacrilimides/alum) to reduce contaminant loading to surface water drainage. These water treatments were primarily intended to address TMDL issues, but the study also will generate additional data on selenium.

The SSSO will be evaluating ecological issues associated with shallow water habitat. They will soon complete a project with USBR funding to revitalize some existing dikes to create shallow water habitats (most about 1 inch deep). The water conditions in these shallow flooded areas will be maintained at levels similar to those that would be representative of effluent from desalination plant by using blended fresh water and Salton Sea water. Water floodup for this project will be done as soon after January 2005 as permitting and compliance issues allow. The system will require approximately 6 months to stabilize before sampling begins (other than the pre-project baseline sampling that will occur beforehand). It is estimated that data from this study will be available in about two years.

DATA GAPS/UNCERTAINTIES

The following discussion of data gaps is based on the review of available data and discussions with personnel from the SSSO, Reclamation, and other regulatory and resource agencies (e.g., DFG, USFWS). During the August 2004 meeting, it was recognized that some data gaps could not be filled within the timeline for the current ecosystem management planning effort, but efforts are underway to fill some data gaps.

The design of ecosystem management alternatives for the Salton Sea will be accomplished using the best available information. However, given inevitable uncertainties about some environmental consequences, any design will require appropriate monitoring and the capability of adaptive management. Data gaps that relate specifically to issues associated with selenium implications of the design aspects of ecosystem management alternatives are given the highest relative importance because they are the most important for evaluations to be completed in the upcoming Ecosystem Management Plan. Data gaps with the secondary level of importance are those related to issues concerning adaptive management for selenium. Data gaps that do not directly relate to design or to adaptive management are assigned to a third level of importance. Using this type of grouping, the data gaps listed below are organized according to how they may relate to ecosystem management for the Salton Sea.

Table 5 provides a brief summary of the availability of selenium data for various environmental media in the Salton Sea ecosystem. This table shows that analytical results are available for abiotic aquatic media (surface water and sediment) at many locations. The exception to this is a lack of surface water data for San Felipe Creek and Salt Creek. Soil data are available for a number of agricultural fields.

Identified Data Gaps Related to Selenium Assessments for Ecosystem Management Plan

The following data gaps relate directly to design considerations for ecosystem management alternatives. As such, these items should be given the highest priority to address prior to completion of the Ecosystem Management Plan. Because of their relative importance, the first group of data gaps are presented in a format that identifies the data gap, explains why the data are needed for the project, describes the proposed action, and the expected duration required to fill the data gap.

Data Gap	Inadequate spatial characterization of selenium in Salton Sea sediment
Input to Project/Need	The distribution of selenium concentrations in sediments in different areas of the Salton Sea will be critical for predicting the selenium effects of different ecosystem management alternatives. In particular, adequate characterization of near-shore sediments will be required to predict conditions in exposed sediments when water

	elevations are lowered. Lack of adequate sediment characterization could lead to more conservative assumptions and greater uncertainties that could increase costs of ecosystem management alternatives.
Proposed Action	Approximately 200-plus surficial sediment samples have recently been analyzed by the USGS and Reclamation. The proposed action is to incorporate these data into the sediment data set for the Salton Sea and to assess the data adequacy. If data gaps are identified by reviewers, then more of the archived sediment samples (or new samples) could be analyzed.
Anticipated Duration	Preliminary analytical results from the first 200 samples were expected in early January. Additional sample analyses of archived samples would require approximately 2 months before the new data were available.

Data Gap	Selenium release and bioavailability characterization of Salton Sea sediments
Input to Project/Need	It was recognized that selenium may be re-mobilized in exposed or irrigated sediments but the magnitude of this problem has not been established. In addition, the bioavailability and toxicity of selenium in sediments will be critical for predicting the selenium effects of different ecosystem management alternatives (such as effects due to changing water quality conditions).
Proposed Action	Collect new samples of sediment from representative areas to use for testing. These sediment composites would be used in bench-scale tests to simulate selenium release conditions under wetting and drying scenarios as well as changing water quality conditions, and to establish a relationship between the water soluble selenium fraction and pooled water. Invertebrates typical of those from the Salton Sea (or surrogates) could be used in the bench-scale tests as bioassays to assess selenium toxicity and uptake from the sediments.
Anticipated Duration	Bioassays and bench-sales tests could take 1 to 2 months to plan and set up, between 1 and 3 months to run, and 1 to 2 months to generate the data.

Data Gap	Further characterization of selenium in Salton Sea biota
Input to Project/Need	Within the Salton Sea and associated freshwater habitats, selenium concentrations in some critical food items have not been adequately characterized. In particular, there are insufficient data for selenium concentrations in benthic and aquatic invertebrates and smaller fish that may represent important exposure pathways for other ecological receptors.
Proposed Action	Collect samples of benthic and aquatic invertebrates (e.g., pileworms) that are not adequately represented in the previous sampling. This will require coordinating a plan with people familiar with the Salton Sea resources to determine the best timing and location for sampling. Look for opportunities to collect samples of fish, including those that have been affected by die-offs. Analyze these additional samples for total selenium and incorporate these data into the biota data set for the Salton Sea.
Anticipated Duration	Undetermined for sampling. Depending on sample availability and numbers, it is expected that the analyses could be completed in 1 to 3 months.

Data Gap	Refine the conceptual site models and food webs
Input to Project/Need	The graphical depiction of food webs and feeding relationships provided by Setmire et al. (1993) is not sufficient for modeling the pathways for selenium transfer and bioaccumulation. More refined conceptual site models and food web information are needed for the various components of the Salton Sea ecosystem, including terrestrial environments. This information will be used to confirm the adequacy of biota sampling, to determine the viability of selenium exposure pathways, and to model bioaccumulation of selenium in various trophic or feeding layers.
Proposed Action	Conduct a literature review and interviews with persons knowledgeable about biological resources in the Salton Sea. Integrate the existing and additional information to refine the conceptual models and food webs. Create graphical representations of the food webs and contaminant pathways for each of the Salton Sea ecosystem components.

Anticipated Duration	Estimated 1 month to complete

Data Gap	Identify and develop tools for predicting selenium concentrations and effects
Input to Project/Need	A quantifiable method for estimating changes in selenium conditions will allow managers to give a consistent weighting for this factor under various management practices and ecosystem management alternatives.
Proposed Action	Coordinate with Theresa Presser/USGS to determine the applicability of existing selenium prediction models (Luoma and Presser, 2000) to the Salton Sea project. This determination will assess the required inputs to the model and the availability of these data for the Salton Sea. Dr. Presser has indicated that she believes the San Francisco Bay model could be adapted for the Salton Sea, but further evaluation and development are needed. If it is determined that the model may prove useful for evaluating selenium in the Salton Sea, then the model may require some adaptation and the Salton Sea inputs will need to be established.
Anticipated Duration	Estimated 3 to 5 months to assess and refine model to suit the Salton Sea conditions

Data Gap	Management practices associated with using the Salton Sea sediment as a vegetation growth medium
Input to Project/Need	This information is needed to determine the approaches for using vegetation in newly-exposed sediments for dust control.
Proposed Action	Submit a portion of the composited sediment samples described above to an analytical laboratory that specializes in agricultural soil testing and crop production recommendations. These samples should be chosen so that they adequately represent sediment areas where vegetation could be used for future dust control. The soil samples will be analyzed for a suite of parameters related to soil fertility and crop production. This task does not assume that plant growth studies will be required.
Anticipated Duration	Estimate 1 month to compete analyses, 1 month for data evaluation.

Data Gap	Site-specific fish and waterfowl consumption information
Input to Project/Need	This information is required to support the evaluation of selenium effects via the fish and waterfowl consumption pathway as part of the human health risk assessment.
Proposed Action	Complete a local survey to assess consumption patterns for people eating fish and waterfowl caught in the Salton Sea.
Anticipated Duration	Estimate 2 to 3 months for planning and execution of the survey

Data Gap	Develop an electronic data set to integrate results for abiotic and biotic media in the Salton Sea ecosystem
Input to Project/Need	An electronic data set will be required for modeling associated with ecological and human health risk characterizations. It is critical that this data set be completed with the results from previous sampling, as well as upcoming analyses (such as those for sediments and bioassays). The data should also be coded by location type to avoid mixing data for areas with different selenium levels and exposure pathways.
Proposed Action	Develop the data base format and transcribe data from hard copy reports along with data quality assignments. Perform QA/QC on the data base before use by ecological and human health risk assessors.
Anticipated Duration	Estimated 1 month from time that final analytical results are available

Identified Selenium Data Gaps Related to Long-term Adaptive Management Strategies

The following data gaps relate to adaptive management issues concerning selenium impacts from implementation of an alternative and the associated monitoring. As such, these data gaps can be addressed as part of the ongoing assessment and management of the chosen ecosystem management alternatives. A critical part of the evaluation of alternatives will be to determine how amenable the alternative will be to adaptive management. The flexibility of an implemented alternative to adaptive management may determine if unforeseen problems can be fixed in the future.

- **Contaminant circulation/cycling** – Circulation and cycling patterns have been documented for the current Salton Sea (Cook et al. 2002; Schroeder et al. 2002), but uncertainties exist regarding how selenium cycling will occur in a restructured and smaller Salton Sea. It is also unknown what the assimilative capacity for selenium will be under the new conditions. While predictive modeling may be useful for evaluation of alternatives, these specific studies should be conducted as part of the monitoring program of the chosen alternative.
- **Selenium conditions in the Imperial and Coachella valleys** – Because irrigation water, used in the farming areas mentioned above, becomes enriched in selenium, it is important to understand more about the selenium distribution and effects in these remote source areas. The existing soil selenium data were collected from non-farmed areas along the west side of the Salton Sea. Initially soil sampling in agricultural areas should be focused where surface water drainage has already shown high selenium mobilization characteristics. Soil sampling should characterize the vertical distribution of selenium in soils through selected continuous core sampling (from surface to tile drain depths) as a way of characterizing the selenium reserve in these soils and to develop source-control alternatives. Using a phased approach, additional sampling of terrestrial organisms (e.g., plants, invertebrates, and small mammals) may be required to assess ecological risks from selenium in these areas as a way to focus on the most effective selenium control options.
- **Telemetry and dietary studies** – Ecosystem management projects will be designed to limit bird and fish exposures to selenium, but it may be important to better understand where and how the exposure is occurring under current conditions. While site-specific selenium data are available for bird and fish species, information regarding locations of uptake for wide-ranging species is lacking because movement (telemetry) studies have not been conducted and dietary (i.e., gut content) information is limited. Any future studies should be focused on known problem areas and the associated species of concern.
- **Nutrient loading** – Algal blooms that result from nutrient loading also remove selenium from the Salton Sea water column. As such, the efforts to reduce nutrient loading to the Salton Sea may be at odds with reducing selenium loads. The modeling of eutrophication cycles in the Salton Sea is under evaluation by Amrhein and Anderson of UC Riverside. Studies similar to these done for the existing Salton Sea, may need to be repeated or refined based on the chosen ecosystem management alternative.

Identified Data Gap Not Directly Related to Management Plan or Adaptive Management

One data gap was identified that did not appear to directly relate to ecosystem design alternatives or adaptive management strategies. This data gap relates to the inadequacy of the fish tissue data set for a revision to the human health fish consumption advisory. While there is interest among stakeholders to revise the fish advisory for selenium in the Salton Sea, it is outside of the scope of the current project, whose focus is to develop and evaluate ecosystem management alternatives. Nevertheless, one of the goals of the ecosystem management actions would be to permit lifting the advisory, if that does not happen in the shorter term. If the fish advisory is to be updated, stakeholders and regulators should agree on the quantity and type of data that will be required to revise the advisory. These data will likely be similar to those needed to monitor selenium in fish to assess the impacts of the chosen ecosystem management alternatives in the future. Realistic fish consumption rates for key fish species, and the long-term viability of these fish populations to sustain current consumption rates, are particularly important.

Summary

The data gaps discussed above were grouped according to their relationship to the ecosystem management design or to the adaptive management requirements of a chosen ecosystem management alternative. The first group contains the list of the most important data gaps that will affect the evaluation and design of ecosystem management alternatives. The second group of data gaps should be considered as part of the adaptive management for the chosen ecosystem management alternatives. The studies to address these data gaps can be developed as part of the monitoring programs that will be required to assess changes in the Salton Sea ecosystem that will follow implementation of the chosen alternative. The last data gap is not directly related to the project, but sampling to fill the gap is similar to what may be done in the future for project monitoring.

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